SPARSITY-BASED RETINAL LAYER SEGMENTATION OF OPTICAL COHERENCE TOMOGRAPHY IMAGES

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Abstract

- Develop novel algorithm for segmentation of optical coherence tomography (OCT) retinal images
- Define graph over sparse representation of image to extract boundaries between retinal layers
- Method can segment between 8 and 11 interlayer boundaries without making overly restrictive anatomic assumptions

Background

Retina

- Layered structure that contains photoreceptors
- OCT measures light backscattered from layers
- Primarily horizontal layers in OCT images
- Morphology used in diagnosis of pathologies

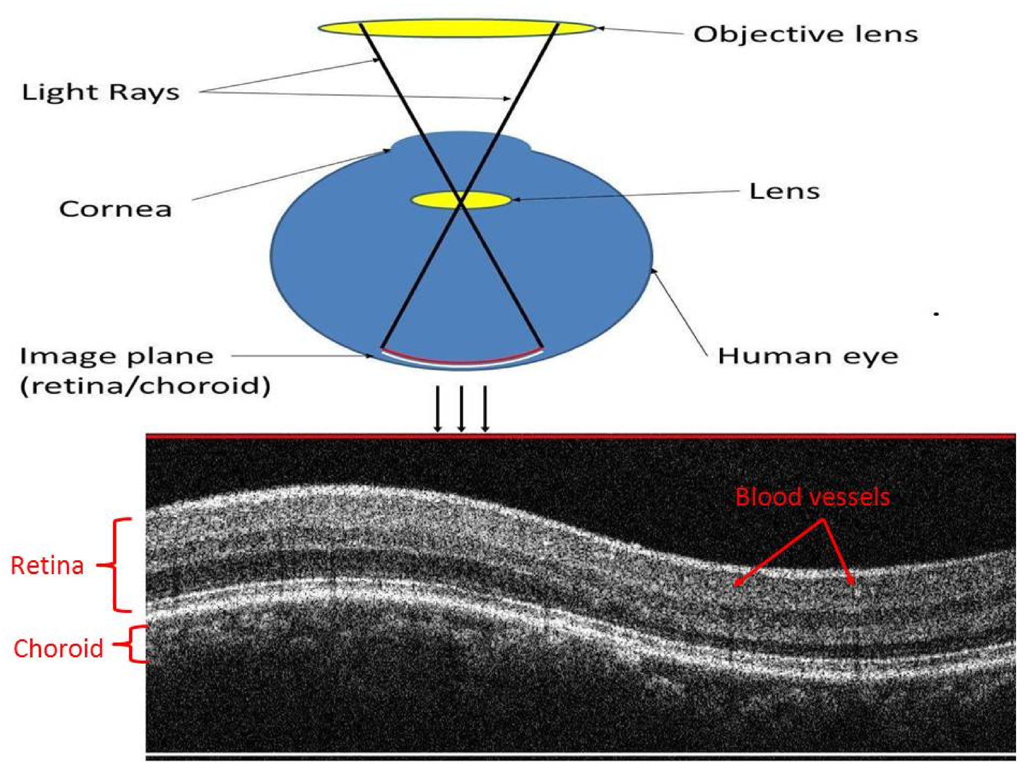

Figure 1: OCT retinal imaging. Top Panel - light incident on retina; Bottom Panel - OCT retinal tomogram

Layer Segmentation Algorithms

- **Columnwise intensity profiling**
  - Sensitive to inhomogeneities
  - Fixed number of layers (4-9)
- **Graph-cut segmentation**
  - Complexity scaling
  - Fixed number of layers (4-9)
  - Restrictive assumptions

Novel Segmentation Algorithm

- Exploits columnwise layer sparseness
- No assumptions about (a) the number of layers or (b) interlayer relationships
- Identifies layers in parallel

Algorithm Flowchart

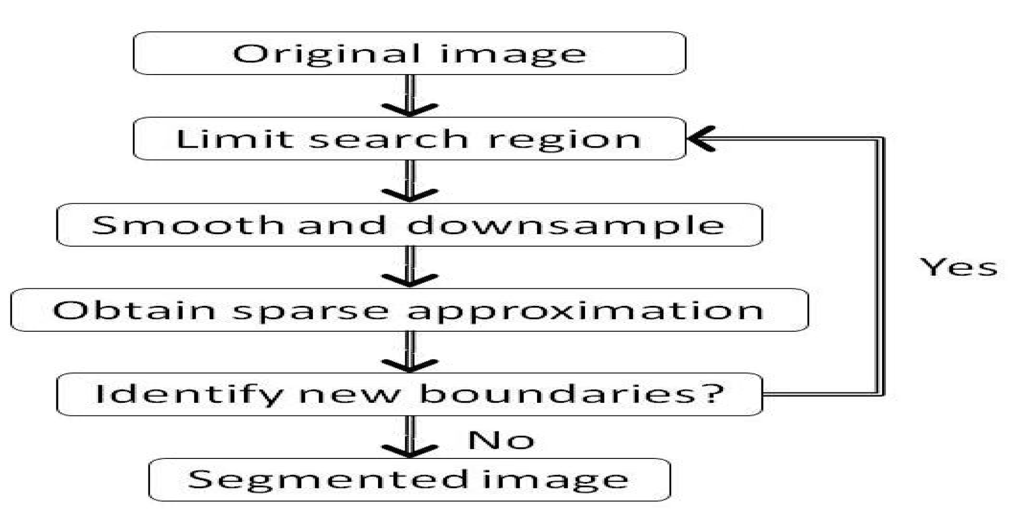

Figure 2: Schematic of layer segmentation algorithm

References

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[2] S. Chiu, X. Li, P. Nicholas, C. Toth, J. Izatt, S. Farsiu, Optics Express **18**(18) (2010), 19413-19428.

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Segmentation Algorithm

Limit search region

- Identify retina and choroid using intensity mask
- Flatten image to top of retina

Figure 3: Initial search region limitation. Left Panel - Original image; Middle Panel - Retina/choroid mask; Right Panel - Image flattened to top of retina

Smooth and downsample

- Median filter across N (eg 20) columns
- Downsample by N

Obtain sparse approximation

- Columnwise sparse approximation via sparse Bayesian learning (SBL) algorithm
- Basis of Heaviside step functions - segments
- Each segment s_i has mean intensity I_{s_i}, position P_{s_i}, front edge height E_{s_i} and length L_{s_i}
- $s_{j:j'}$ denotes combination of adjacent segments

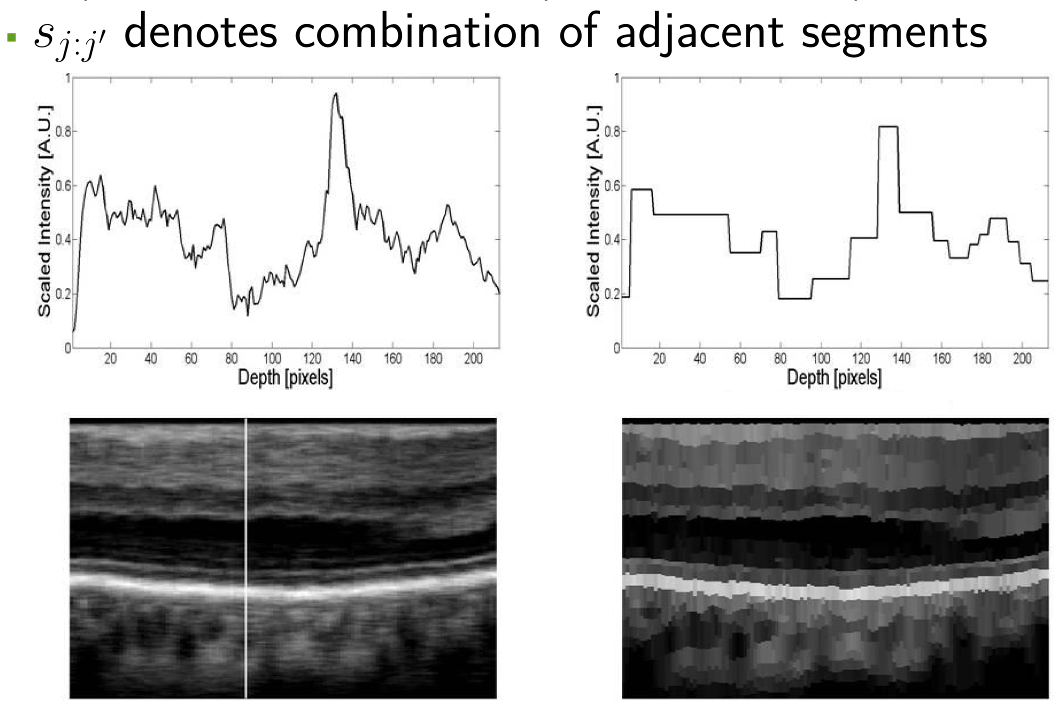


Figure 4: Sparse approximation of single column. Top Left Panel - Single column from image; Top Right Panel - Sparse approximation of single column; Bottom Left Panel - Image; Bottom Right Panel - Sparse approximation of image

Identify new boundaries

- **Build Layers**
  - Use graph theory to group segments into layers that extend across columns
  - I_{l_j}, P_{l_j}, E_{l_j}, L_{l_j} defined by local averages

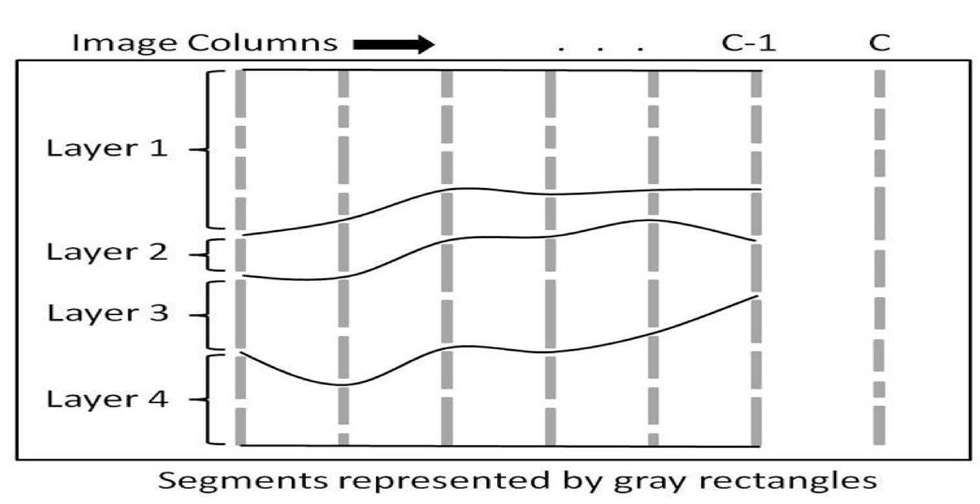


Figure 5: Layer building formulation - Seek assignment of layers in columns 1:C-1 with segments in column C

- Node b_{ij} denotes segment i begins layer j; node e_{ij} denotes segment i ends layer j
- Node is reachable only if segments are close to layers ($|P_{l_j} - P_{s_i}| \leq 3$)
- Layer extension transition ($b_{ij} \to e_{i'j}$) - segments $s_{i:i'}$ extend layer l_j

$$Cost = \alpha|I(l_j) - I(s_{i:i'})| + \beta|L(l_j) - I(s_{i:i'})| \quad (1)$$

if $i \geq i'$ and is otherwise infinite

- All layer extension transition ($e_{ij} \to b_{i'j+1}$) - no layer skipping

$$Cost = \gamma|E(l_{j+1}) - E(s_i)| \quad (2)$$

if $i \geq i'$ and is otherwise infinite

- Merge transition ($b_{ij} \to e_{i'j'}$) - merge layers $l_{j:j'}$

$$Cost = \alpha|I(l_{j:j'}) - I(s_{i:i'})| + \beta|L(l_{j:j'}) - I(s_{i:i'})| \quad (3)$$

if $i \geq i'$ and $j' = j + 1$ and is otherwise infinite

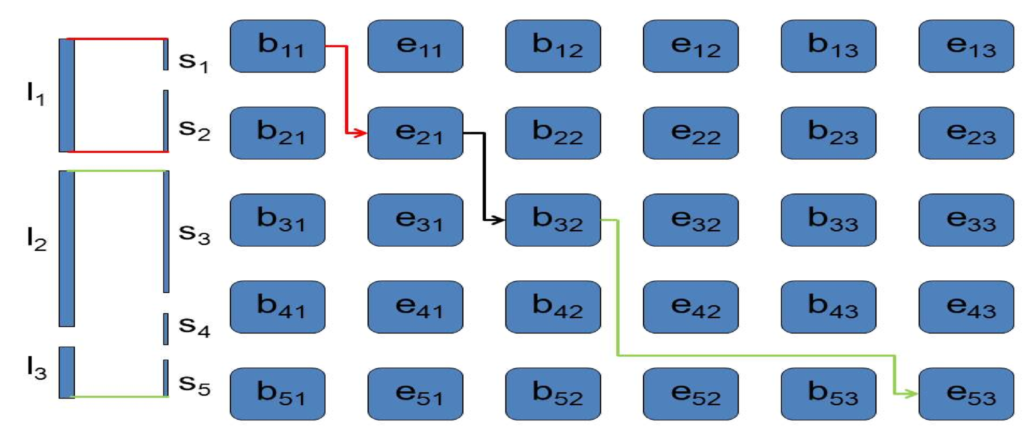


Figure 6: Sample graph traversal. Layer 1 extended by segments 1 and 2; layers 2 and 3 merge.

- Djikstra's algorithm to solve single source shortest path problem from b_{11} to e_{SL}

- **Prune Interlayer Boundaries** -
  - Layer building may result in faulty boundaries/layers
  - Test boundary using gradient and consistency
- **Initialization**
  - Initialize layers in first column
  - Set each segment to distinct layer - merge as move across columns

Iterate

- Restrict search space between adjacent reliable interlayer boundaries
- Repeat algorithm until no new layers are found

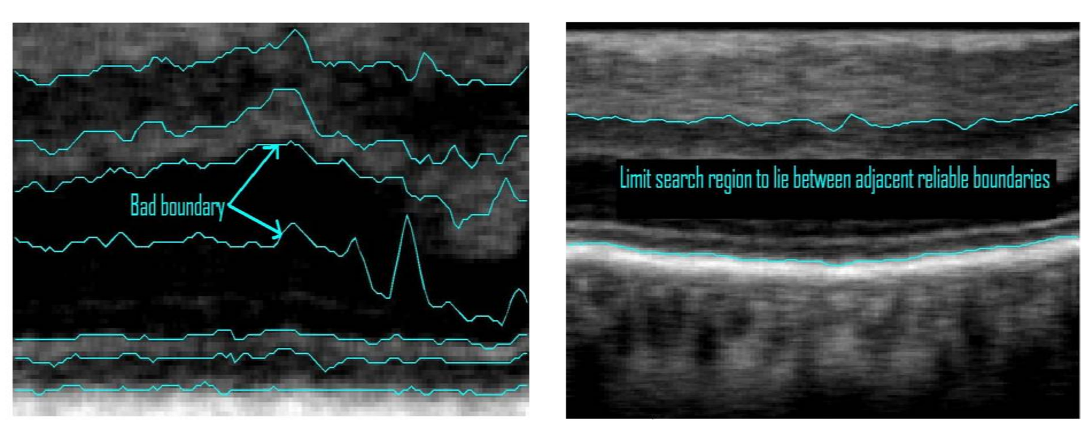
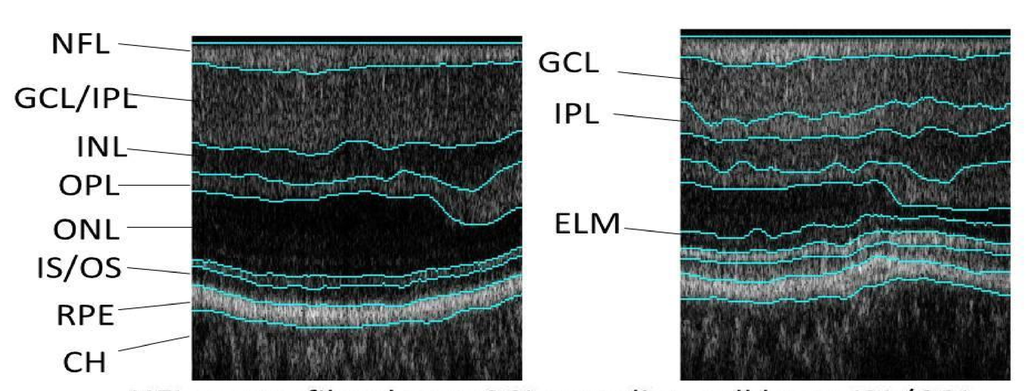


Figure 7: Left Panel - interlayer boundary pruning; Right Panel - search space reduction using reliable boundaries

Results

- Scanned 2 eyes a total of 12 times each
- Found 8-11 boundaries on all scans (other algorithms find 9 at most)



NFL: nerve fiber layer, GCL: ganglion cell layer, IPL/OPL: inner/outer plexiform layer, INL/ONL: inner/outer nuclear layer, ELM: external limiting membraneIS/OS: inner/outer segment, RPE: retinal pigment epithelium, CH: choroid

Figure 8: Segmentation results for 2 eyes

Conclusions and Future Work

- Algorithm segments between eight and eleven layer boundaries without making overly restrictive anatomic assumptions
- Sparse representation can be used as preprocessing step in other graph-based segmentation algorithms
- Plan to optimize system parameters via statistical means as well as extend algorithm to handle pathological retinas

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